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Original communication

Age and sex estimation by metric measurements and fusion of hyoid bone in a Turkish population

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ABSTRACT

The hyoid bone is of great importance in forensic medicine practice and it has been studied for various forensic purposes; however, there have been few studies dealing with age and sex estimation using the hyoid bone. Using discriminant function analysis this study attempts to determine the utility of metric measurements and non-metric variations of the hyoid bone in terms of estimation of sex and age in a Turkish population and to find out differences with other populations by comparison of obtained results with the literature. For this purpose, the hyoid bones of 85 cadavers of known sex and age were extracted and 33 measurements were made with a computer program following photography with a camera. In addition to these measurements, the degree of fusion of the greater cornua to the hyoid corpus was examined. Out of 33 measurements, 18 showed significant sex-related differences.

There was a sharp rise in hyoid bone fusion in both males and females after the age of 60 years. However, no marked sex-related differences were observed regarding fusion. The unstandardised canonical discriminant function was estimated based on three variables, and the correct classification ratio was 77.4% for males and 81.3% for females. The obtained findings suggest that measurements of hyoid bone can be used for sex estimation in the Turkish population.

1. Introduction

Among the targets of medico-legal investigation establishing the identity of a deceased plays a crucial role, particularly in the examination of dismembered, burned, severely mutilated corpses or skeletal remains. In such instances, estimating the age, sex and stature of victims is vital, which might be achieved through evaluation of the developmental changes of the bones. Variations in cranial sutures, teeth and various bones and body parts have previously been studied for this purpose.[1–4]

The hyoid bone is of great importance in forensic medicine as its fractures are considered as evidence for strangulation or hanging. Furthermore, fractures of the hyoid bone can be evidence of neck injuries especially in decomposed bodies and skeletal remains without soft tissue.[5] In addition, the hyoid bone, especially its corpus, is considered as a useful means for sex estimation in archaeological and forensic investigations.[6] The degree of fusion of the greater cornua with the body of the hyoid bone might be helpful in age estimation, in severely mutilated and decomposed bodies without other skeletal remains.[7] In the literature, there have been many studies regarding fractures of the hyoid bone. However, a lesser number of studies have focussed on sex and age determination using the characteristics of the hyoid bone.[6,8,9] Morphometry and sexual dimorphism in the adult human, by discriminant function analysis, is reported to be population-specific.[10]

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The purpose of this study was to find the utility of the hyoid bone in estimation of sex and age based on metric and non-metric parameters in a Turkish population using discriminant function analysis. This is first-ever study from Turkey on the subject and our results will be compared with the results obtained in previous studies from other population groups.

2. Materials and methods

Ethical approval was obtained from the scientific committee of The Council of Forensic Medicine. Corpses autopsied in the Morgue Department of Ankara Group Administration of the Council of Forensic Medicine were used as cadavers. Hyoid bones of 85 (53 male and 32 female) cadavers were extracted in order to obtain metric measurements and evaluate non-metric variations of the hyoid bone. Afterwards, the hyoid bones were carefully separated from the thyroid cartilage and the adherent tissue was removed. Extracted hyoid bones were put on a black background and photographed from superior–inferior and the front at a distance of 55 cm with a digital camera (Samsung Digimax S500). Lastly, for each hyoid bone 33 measurements were taken, using a computer program (Corel Draw 12, 2003 Corel Corporation, Ottawa, Ontario, Canada), first described by Miller et al.[5] and then used by Kim et al.[11] The measurements consisted of 21 lengths, seven widths and five angles (Fig. 1(a)–(c)) (Table 1). In addition to these measurements, the degree of fusion of the greater cornua to the hyoid bone was examined.

Cases involving compression of the neck and/or fracture of the hyoid bone, individuals <21 years of age and decomposed bodies were excluded from the scope of the study. In order to observe age-related differences, all decades up to 80 years are represented by inclusion of at least few cases from each. The age of cases ranged between 21 and 80 years (Table 2).

Discriminant analysis was performed using Statistical Package for the Social Sciences (SPSS version 16.0, SPSS Inc., Chicago, IL, USA). Independent samples *t*-test was used to analyse differences regarding 33 measurements among males and females.

3. Results

3.1. Metric measurements

In the present study, the studied cases (53 male and 32 female) were aged between 21 and 80 years. Males showed a significantly larger hyoid than females for 18 measurements out of 33 ($P < 0.05$). Out of these 18 measurements, 12 were the length measurements and six were width measurements. The hyoid measurements and P values are shown in Table 3.

The variable that sets the Wilk's λ at a minimum was selected using stepwise statistics. Each step was statistically significant with a P value of <0.001. These variables consist of three measurements: first, seventh and 30th. Standardised canonical discriminant function coefficients of each variable were 0.530, 0.634 and 0.450 (Table 4). The canonical correlation was 0.56 and the eigenvalue was 0.462. The higher the canonical correlation and the closer the eigenvalue to 1, the higher the discrimination ability was. Wilk's λ eigenvalue of a canonical discriminant function was 0.653 with $P < 0.001$, which indicated a statistically significant discriminant score differences between groups. Unstandardised canonical discriminant function coefficients of variables are shown in Table 4.

The unstandardised canonical discriminant function equation was estimated using these three variables:

Discriminant function
$(D) = +(0.062 \times X_1) + (0.130 \times X_2) + (0.269 \times X_3) - 10.542$

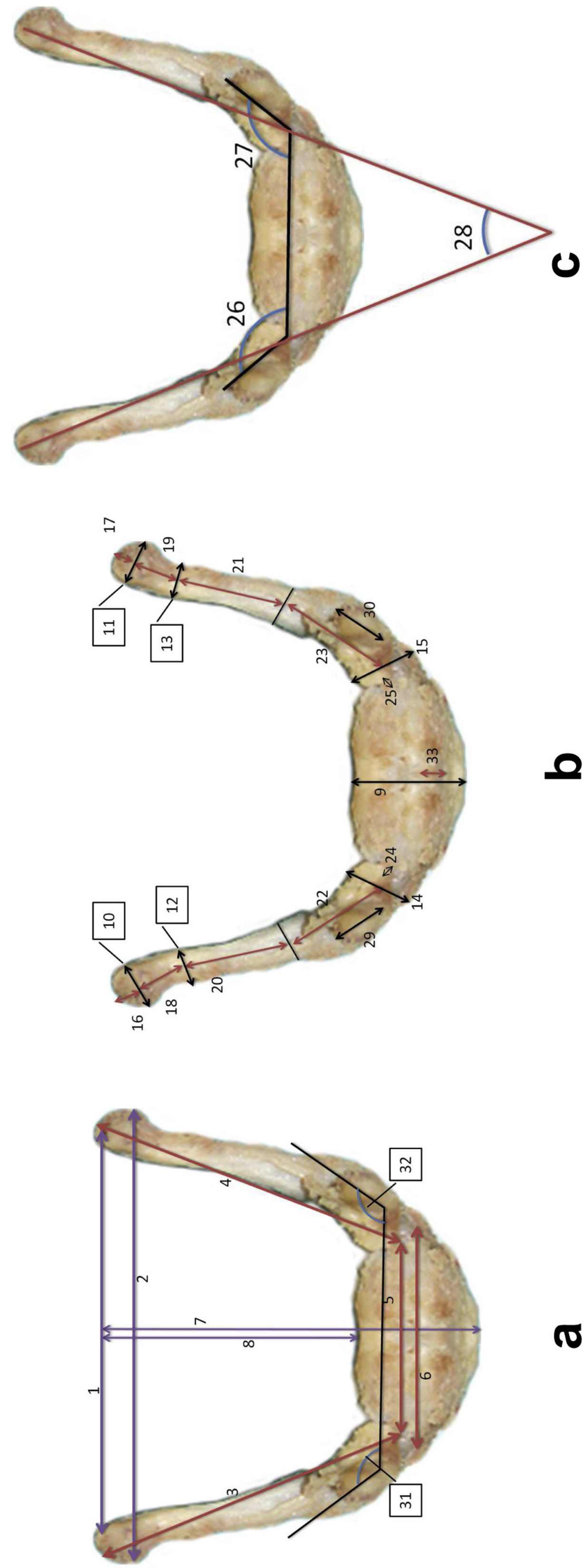

Fig. 1. (a)–(c): Measurements of hyoid bone.

Table 1
Osteometric measurements of the hyoid bone.

Length	
1	Length between the distal ends of the right and left greater cornua (centre point)
2	Length between the distal ends of the right and left greater cornua (parietal point)
3, 4	Maximum length of greater cornua (right and left)
5	Length from the middle of the left joint space to the middle of the right joint space (across the body of the hyoid bone)
6	Length from the centre point of the left side of the body of the hyoid bone to the centre point of the right side of the body of the hyoid bone (through the central axis of the body of the hyoid bone)
7	Perpendicular length from the centre point of a line between the distal ends of the right and left greater cornua to the centre point of the anterior view of the body of the hyoid bone
8	Perpendicular length from the centre point of a line between the distal ends of the right and left greater cornua to the centre point of the posterior view of the body of the hyoid bone
16, 17	Length form the distal end of the left greater cornua to the centre point of the broadest segment of the distal end of the greater cornua (through the central axis of the greater cornua) (right and left)
18, 19	Length from the centre point of the broadest segment of the distal end of the greater cornua to the centre point of the narrowest segment of the greater cornua (through the central axis of the greater cornua) (right and left)
20, 21	Length from the narrowest segment of the greater cornua to an equidistant point between the distal and proximal ends of the greater cornua (through the central axis of the greater cornua) (right and left)
22, 23	Length from an equidistant point between the distal and proximal ends of the greater cornua to the broadest part of the proximal end of the greater cornua (through the central axis of the greater cornua) (right and left)
24, 25	Length from the centre point of the proximal end of the greater cornua to the centre point of the same side of the body of the hyoid bone (not in bones that the greater cornua are synostosed to the body of the hyoid bone)
29, 30	Maximum length of the lesser cornua) (right and left)
33	Length of the cornua of the body of the hyoid bone
Width	
9	Width of the body of the hyoid bone at its centre point (perpendicular to the surface of the bone)
10, 11	Maximum diameter of the distal end of the greater cornua (perpendicular to the internal surface of the bone) (right and left)
12, 13	Minimum diameter of the distal end of the greater cornua (perpendicular to the internal surface of the bone) (right and left)
14, 15	Maximum width of the proximal end of the greater cornua (perpendicular to the internal surface of the bone) (right and left)
Angles	
26, 27	Angle of length from the middle of the left joint space to the middle of the right joint space (across the body of the hyoid bone) and length from an equidistant point between the distal and proximal ends of the greater cornua to the broadest part of the proximal end of the greater cornua (through the central axis of the greater cornua) (right and left), angle of 5 and 22(23)
28	Angle of right and left greater cornua length (long axis of greater cornua)
31, 32	Angle of lesser cornua and length from the middle of the left joint space to the middle of the right joint space (across the body of the hyoid bone) (right and left)

These variable were as follows: X_1 is the first measurement as the distance between the distal ends of the right and left greater cornua, X_2 is the seventh measurement as the perpendicular length from the centre point of a line between the distal ends of the right and left greater cornua to the centre point of the anterior view of the body of the hyoid bone and X_3 is the 30th measurement as the maximum length of the left lesser cornua.

In the classification results, the hit ratio was 77.4% for males, 81.3% for females and for the original and cross-validated groups they were 77.4% and 78.1%, respectively (Table 5).

Considering all 33 measurements, 92.5% of males and 78.1% of females were correctly classified using discriminant functions.

Table 2
Age and sex distribution.

Age (years)	Males	Females	Total
21–30	11	9	20
31–40	11	9	20
41–50	13	5	18
51–60	7	2	9
61–70	8	2	10
71+	3	5	8
Total	53	32	85

3.2. *Fusion of greater cornua*

3.2.1. *Females ($n = 32$)*

There was bilateral non-fusion in 6 (18.7%) cases, fusion of one side in 8 (25.0%) and fusion of both sides in 18 (56.3%) cases. Among females aged between 21 and 30 years ($n = 9$), there was unilateral fusion in only one case, bilateral fusion in four cases and bilateral non-fusion in four cases. Among females aged between 31 and 40 years ($n = 9$), three showed unilateral fusion, four showed bilateral fusion and two showed bilateral non-fusion. Among females aged between 41 and 50 years ($n = 5$), bilateral fusion was observed in one case while unilateral fusion was observed in remaining four cases. However, all females older than the age of 50 ($n = 9$) showed bilateral fusion (Table 6).

3.2.2. *Males ($n = 53$)*

Among males, bilateral non-fusion was observed in 6 (11.4%) cases, while unilateral fusion was observed in 12 (22.6%), and

Table 3
The distribution of average and *p* values for osteometric measurements of the hyoid bone.

	P	Male ($n = 53$)		Female ($n = 32$)	
		Mean	Std. deviation	Mean	Std. deviation
1	0.00	45.50	7.31	38.47	10.17
2	0.00	49.16	6.79	42.44	9.12
3	0.00	35.39	3.82	31.32	4.44
4	0.01	33.71	3.40	31.56	4.15
5	0.00	22.50	3.41	20.71	3.96
6	0.03	26.28	3.94	23.62	3.89
7	0.00	44.56	5.03	38.66	5.07
8	0.00	34.17	3.99	30.03	4.30
9	0.03	9.46	1.27	8.86	1.19
10	0.01	5.23	1.05	4.57	1.13
11	0.00	5.38	1.05	4.63	0.97
12	0.04	4.44	0.85	4.03	0.92
13	0.01	4.53	0.89	3.93	1.06
14	0.05	7.79	0.83	7.39	1.08
15	0.03	7.57	0.84	7.10	1.06
16	0.40	3.78	0.58	3.65	0.75
17	0.07	3.93	0.61	3.67	0.72
18	0.36	3.83	0.69	3.69	0.65
19	0.78	3.91	0.59	3.96	0.71
20	0.70	11.60	2.24	11.40	2.54
21	0.58	11.09	2.09	10.80	2.55
22	0.00	16.34	2.90	13.96	2.17
23	0.00	15.41	2.53	13.86	2.17
24	0.86	2.98	0.44	2.96	0.65
25	0.39	3.11	0.44	3.00	0.61
26	0.33	123.55	11.71	125.78	7.17
27	0.41	123.96	8.62	125.34	4.94
28	0.41	45.45	8.86	43.63	11.48
29	0.01	9.12	1.63	8.21	1.57
30	0.01	9.20	1.64	8.15	1.73
31	0.91	151.85	11.84	151.56	10.53
32	0.78	146.75	10.51	146.06	11.64
33	0.68	3.45	0.60	3.51	0.70

Table 4
Discriminant function coefficients of the hyoid bone.

	Standardised canonical discriminant function coefficients	Canonical discriminant function coefficients[a]
1 (X_1)	0.530	0.062
7 (X_2)	0.654	0.130
30 (X_3)	0.450	0.269
(Constant)		−10.542

[a] Unstandardised coefficients.

Table 5
Probabilities of group membership of the hyoid bone[b,c]

		Sex	Predicted group membership		Total
			Males	Females	
Original	Count	Males	41	12	53
		Females	6	26	32
	%	Males	77.4	22.6	100.0
		Females	18.8	81.3	100.0
Cross-validated[a]	Count	Males	41	12	53
		Females	7	25	32
	%	Males	77.4	22.6	100.0
		Females	21.9	78.1	100.0

[a] Cross validation is done only for those cases in the analysis. In cross validation, each case is classified by the functions derived from all cases other than that case.
[b] 77.4% of original grouped cases correctly classified.
[c] 78.1% of cross-validated grouped cases correctly classified.

bilateral fusion was observed in 35 (66.0%) of cases. Out of males aged between 21 and 30 years ($n = 11$), three had unilateral fusion, six had bilateral fusion and four had bilateral non-fusion. Out of 11 cases aged between 31 and 40 years, 6 showed unilateral fusion, 4 showed bilateral fusion and 1 showed bilateral non-fusion. Out of 13 cases aged between 41 and 50 years, 3 had unilateral fusion, 8 had bilateral fusion and 2 had bilateral non-fusion. All males aged over 60 years had bilateral fusion of the hyoid joints (Table 6).

A sharp rise in the rate of hyoid bone fusion was observed in both males and females after the age of 60 years. In fact, all of these showed bilateral fusion. However, there were not any marked sex differences in fusion.

Comparison of measurements 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 22, 23, 29 and 30 of the presented series with those from other countries revealed that all measurements, of our series, in both the males and females yielded higher values than North American[5] and Korean subjects,[11] which indicates racial differences of population characteristics (Table 7).

4. Discussion

Identification of whole or a part of skeleton is a common issue in forensic science practice, particularly in forensic anthropology and its solution requires techniques and expertise from a number of disciplines.[12] Identification of decomposed or skeletonised remains is often performed with the help of an anatomist, anthropologist, dentist, radiologist and serologist.[13] In this regard, age and sex estimation is the most frequent task through investigation of human remains.

4.1. Metric measurements

There have been studies dealing with metric measurements and non-metric variations of the hyoid bone for age and sex estimation in cadavers.[5–11,15–19] In the present study, both metric and non-metric methods were used.

The male hyoid bones were significantly larger than female hyoid bones for 18 out of 33 measurements. In accordance with this, in Kim et al.'s study[11] the measurements of male hyoids were significantly larger than females' for 21 out of 34 measurements. Similarly, Mukhopadhyay's study[16] revealed that the hyoids in male were wider and longer than those in females, which was stated to be statistically significant. Additionally, Miller et al.[5] reported that the hyoid bone was significantly larger in the males than in the females and that some measurements showed more sexual dimorphism. Reesink et al.[6] also revealed that the female hyoid bones were smaller, but that only three out of 13 measurements showed statistically significant differences between the sexes. Kim et al.,[11] using discriminant analysis and 20 metric measurements, showed a high rate of sex estimation, and reported that a combination of the 6th, 15th and 20th measurements provided an accuracy of 88%. Miller et al.[5] showed that the accuracy of discriminant function using five measurements (1st, 5th, 11th, 20th and 19th) was 69.2% in males and 75.2% in females. However, Reesink et al.[6] claimed that a reliable estimation of sex based on one measurement of the hyoid bone was not possible by performing a study comprising 13 measurements of the hyoid bone in 59 cases. They added that a cross-validated model, using three measurements, can improve the a priori probability of 50–76%.

In the present study, the unstandardised canonical discriminant function was estimated based on three variables, and the classification results showed the hit ratio to be 77.4% for males and 81.3% for females. Using all 33 measurements provided correct classification as 92.5% of males and 78.1% of females. Measurements apart from 1, 7 and 30 were not contributive to discrimination for

Table 6
Fusion of hyoid bones in females and males.

Age (years)		Male				Female			
		Unilateral fusion	Bilateral fusion	Bilateral nonfusion	Total	Unilateral fusion	Bilateral fusion	Bilateral nonfusion	Total
21–30	*n*	3	6	2	11	1	4	4	9
	%	27.3	54.5	18.2	100.0	11.2	44.4	44.4	100.0
31–40	*n*	6	4	1	11	3	4	2	9
	%	54.5	36.4	9.1	100.0	33.3	44.4	22.3	100.0
41–50	*n*	3	8	2	13	4	1	0	5
	%	23.1	61.5	15.4	100.0	80.0	20.0	0.0	100.0
51–60	*n*	0	6	1	7	0	2	0	2
	%	0.0	85.7	14.3	100.0	0.0	100.0	0.0	100.0
61–70	*n*	0	8	0	8	0	2	0	2
	%	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
71+	*n*	0	3	0	3	0	5	0	5
	%	0.0	100.0	0.0	100.0	0.0	100.0	0.0	100.0
Total	*n*	12	35	6	53	8	18	6	32
	%	22.6	66.0	11.4	100.0	25.0	56.3	18.7	100.0

Table 7
Comparisons of measurements of the hyoid bone between countries (unit: mm, mean ± SD).

Measurement	North American (1998)[5]		Korean (2006)[11]		Turkey (this study)	
	Males ($n = 182$)	Females ($n = 125$)	Males ($n = 52$)	Females ($n = 33$)	Males ($n = 53$)	Females ($n = 33$)
1	39.8 ± 9.3	40.1 ± 8.1	42.8 ± 12.3	31.6 ± 16.2	45.50 ± 7.31	38.47 ± 10.17
2	–	–	45.8 ± 12.8	35.4 ± 16.1	49.16 ± 6.79	42.44 ± 9.12
3	28.3 ± 5.2	27.3 ± 4.5	34.8 ± 6.0	27.6 ± 10.7	35.39 ± 3.82	31.32 ± 4.44
4	28.3 ± 5.2	27.5 ± 4.2	33.5 ± 7.3	28.0 ± 9.3	33.71 ± 3.40	31.56 ± 4.15
5	21.4 ± 3.4	19.8 ± 3.0	22.3 ± 2.3	19.3 ± 2.2	22.50 ± 3.41	20.71 ± 3.96
6	0.7 ± 0.9[a]	0.6 ± 0.7[a]	26.0 ± 2.5	22.4 ± 2.4	26.28 ± 3.94	23.62 ± 3.89
7	35.2 ± 5.8	32.7 ± 4.7	39.7 ± 3.2	33.9 ± 6.6	44.56 ± 5.03	38.66 ± 5.07
8	27.3 ± 5.1	25.3 ± 4.2	31.5 ± 4.5	27.0 ± 5.6	34.17 ± 3.99	30.03 ± 4.30
9	7.9 ± 1.8	7.4 ± 1.6	7.8 ± 1.6	7.1 ± 1.2	9.46 ± 1.27	8.86 ± 1.19
10	3.3 ± 0.9	3.5 ± 0.8	4.2 ± 1.0	3.6 ± 1.6	5.23 ± 1.05	4.57 ± 1.13
11	3.3 ± 1.0	3.5 ± 0.8	3.8 ± 1.1	3.1 ± 1.3	5.38 ± 1.05	4.63 ± 0.97
12	2.0 ± 0.5	2.1 ± 0.6	2.9 ± 0.6	2.6 ± 1.1	4.44 ± 0.85	4.03 ± 0.92
13	2.1 ± 0.6	2.1 ± 0.6	2.6 ± 0.9	2.2 ± 0.9	4.53 ± 0.89	3.93 ± 1.06
15	5.0 ± 1.2	4.7 ± 0.9	5.5 ± 0.8	4.2 ± 1.2	7.57 ± 0.84	7.10 ± 1.06
22	3.1 ± 1.1a	2.7 ± 1.0a	13.1 ± 2.1	10.7 ± 3.2	16.34 ± 2.90	13.96 ± 2.17
23	11.3 ± 2.9	11.2 ± 2.3	13.1 ± 1.8	11.1 ± 3.1	15.41 ± 2.53	13.86 ± 2.17
29	–		2.6 ± 4.4	1.1 ± 2.1	9.12 ± 1.63	8.21 ± 1.57
30	–		1.8 ± 2.4	1.1 ± 1.9	9.20 ± 1.64	8.15 ± 1.73

[a] This measurements are not appropriate with the allegedly measured area.

females; thus, using all 33 measurements reduced the classification rate for females. On the contrary, the classification rate was increased for males by using all measurements.

5. Fusion of greater cornua

The use of fusion of the greater cornua to the body of the hyoid bone for age estimation in a badly decomposed or partially skeletonised human body is limited in forensic science. Although there seems to be a trend towards higher frequency of fusion with increasing age, significant numbers of middle-aged and elderly people, especially women, might show non-fusion.[14]

It is true that the likelihood of complete ossification in an individual's hyoid bone may increase with age, and in such cases the hyoid bone would be more susceptible to fracture due to loss of elasticity. However, a significant number of elderly people might have persistent, flexible greater cornua joints.[14]

Gupta et al., in a study in 2008,[7] noted that fusion of the greater cornua to the body of the hyoid bone increased with age in both males and females. Shimizu et al.[19] reported that there were morphological changes and sex differences in the hyoid bone with ageing, which was attributed to the morphological changes to the fusion between the body and the greater cornua. Miller et al., in their study on 315 hyoid bones,[5] showed a significant variation in fusion of the greater cornua to the hyoid body depending on age. They reported that although the number of people with bilateral fusion increased, most of the elderly people had either unilateral or bilateral non-fusion.

The study by Miller et al. did not reveal a significant difference in the number of individuals with bilateral fusion between males and females. They also found little evidence for sex differences in the age at which the greater cornua fuse.

In a study by Gupta et al.,[7] the frequency of hyoid bone fusion increased sharply after 50 years of age and all the hyoid bones were bilaterally fused after 60 years of age. They reported no significant differences in the fusion pattern of the hyoid bone on the left and right sides and that fusion occurred earlier in females than in males by about 5 years.

In accordance with the literature,[5,7] the results of the present study showed a considerable age variation in fusion of the greater cornua to the hyoid body. Furthermore, an interpretation of limited number of cases revealed that both males' and females' hyoid bone fusion showed a sharp rise after the age of 60 years, and all cases aged over 60 years showed bilateral fusion. Conversely, Harjeet et al. reported that subjects over 60 years of age showed either unilateral (13.2%) or bilateral (42.1%) non-fusion or fusion (21.1% bilateral, 13.2 unilateral).[18] In this respect, as Harjeet et al. stated, [18] because of widely different findings and arising controversies using fusion of hyoid bone for estimation of age seems not be a reliable method.

6. Conclusion

On comparing the hyoid measurements obtained in this study with those reported from other countries, all measurements showed higher values than those of North American and Korean subjects, which might be indicative of racial differences and population characteristics in morphometrics of the hyoid bone.

The findings of the present study suggest that measurements of hyoid bone can be utilised for sex estimation in the Turkish population. Using all 33 measurements provided correct classification in 92.5% of males and 78.1% of females. On the other hand, the unstandardised canonical discriminant function was estimated based on three variables, and the correct classification ratio was 77.4% for males and 81.3% for females. Future studies dealing with the features of two or more bones will help to achieve more accurate age and sex estimation rates.

Because of widely different findings and arising controversies, using hyoid bone fusion for estimation of age does not seem to be a reliable method.

7. Limitations

Besides being similar to previously published literature, the sample size was too small to draw strong conclusions. Further studies with larger series need to be performed to reach more reliable results.

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Contributorship statement
All authors included in the authors list have contributed to the data collection, data evaluation, writing of manuscript, language

use and etc. And no professionals other than authors contributed to any of the process during article preparation.

Conflict of interest

There are no competing interests for any of authors.

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